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BALL BANK STUDY

FOR HORIZONTAL CURVES

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INSTRUMENTS THAT HELP YOU "MAKE THE GRADE"

BALL BANK, HORIZONTAL CURVE STUDY

Run Number	Run Speed	Ball Bank Reading in Degrees			
		NB	SB	EB	WB
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

SAFE SPEEDS ON CURVES: A HISTORICAL PERSPECTIVE OF THE BALL BANK INDICATOR

By David R. Merritt

In the early days of transportation, travel ways were built to accommodate the walker and the horse rider: gradually they were improved to accommodate horsedrawn carriages and wagons, stagecoaches, and finally the "horseless carriage" or motor vehicle. Vehicle speeds in early days of transportation averaged from 3 to 8 miles per hour, and the travel ways included paths, log roads, clearings through forests, and widened trails around and over the hills and across the far-reaching valleys.

In the early 1900's the self-powered motorized vehicle appeared. Almost overnight the system of roads and trails had to be changed to accommodate these vehicles. Mass production beginning in the 1920's made these vehicles available to the general public. The top speeds of these ever improving vehicles increased from 25 miles per hour to greater than 40 or 50 miles per hour. The road surfaces were hand paved and dustproof, thus allowing higher speeds. Drivers' speeds increased in relation to the increased capability and power of their motor vehicles.

THE BALL-BANK READING IS A MEASURE OF THE CENTRIFUGAL FORCES.

An adverse effect brought about by higher speeds, more vehicles and inadequate roadways was a significant increase in accidents. Run off road accidents on curves were not uncommon in the early days, as motor vehicles used roadways that were designed for the horse and buggy. The public demanded more and improved roadways that would match the capability of the vehicles.

Early Highway Design

During this early period, there was little or no uniformity or consistency in highway engineering practice. Roadways generally matched the terrain and were merely widened pathways in some cases. Long, straight sections predominated in flat areas: in the hilly and mountain areas, the highways were cut through the slopes of the existing terrain. It was not until the early turnpike building era that roadways were built to accommodate faster vehicles.

On long tangent sections, vehicle speeds were usually high as the vehicles's capabilities would allow and the risk the driver was willing to assume. The driver was expected to slow down when traveling a curved portion of the highway. Just how much the driver should slow down was an independent decision based on experience and judgment. Sometimes, due to the driver's misjudgment of the sharpness of a curve, the vehicle would run off the road or collide head on with an oncoming vehicle. Speeds on sharper curves were sometimes considerably less than those on the approaching roadways, and in most cases, they were lower than the posted speed limits on what was considered maximum safe and reasonable speed.

For economic and practical reasons, curved sections of highways need to be a part of the overall design and layout of the highway system. The concept of balanced design, first proposed in the early 1930's, was an attempt to have tangent sections of highway connected with curved portions all designed to be driven at the same speed. It would thus not be necessary for the driver to slow down in order to safely traverse the curved sections of a highway facility.

Superelevation

Some of the early travel design engineers, working in the 1920's and 1930's began their careers as railroaders. They knew that the railroad tracks could be slightly "banked" on the curves to counteract the outward forces of the railroad cars as they traveled a curve. On straightaways, the track rails were level with one another, but on curved sections one rail was higher than the adjacent rail; this allowed a railroad train to travel at about the same speed on the curves as on the tangent straight sections of track.

This effect was applied to roadway design and was known as superelevation. The balanced design concept used superelevation on highway curves to allow motor vehicles to be safely driven at about the same reasonable speed over the entire facility. Top speeds of motor vehicles had by this time risen to 60 mph or above, and the numbers and severity of accidents were at an all-time high.

Recognition of Speed-Curve Relationship

During 1935 the United States government's road building agency, the Bureau of Public Roads, began research testing of safe driving speeds of curves. Prior to that, there was considerable disagreement among many renowned people as to what constituted a satisfactory procedure for determining safe speeds on curves. Because of this disagreement and recognizing that the

increased speeds of motor vehicles brought centrifugal forces that were beyond what could be practically counteracted by superelevation of curves, BPR in 1985 issued instructions for measuring curvature and superelevation and defined maximum safe speed under normal driving conditions.

Maximum safe speed was defined as the minimum speed at which the centrifugal force created by the movement of a vehicle around the curve causes the driver or passenger to feel a "side pitch outward." It was felt that skidding would occur at much higher speeds: therefore, a sufficient margin of safety against out-of-control skidding would be present at speeds at which the initial "side pitch" was first noticed. This was the criterion used to identify driver discomfort as correlated with the centrifugal force sensation. It was later known as the "driver's judgment of incipient instability."

In response to PBR's invitation for experimental test data based on the controlling criteria, 900 road tests involving several hundred volunteer drivers were sent from various states and evaluated by BPR. Using the basic side friction formula $E + F - 0.671 /R$, in which E represents the superelevation slope, F the side friction factor, V the velocity of the vehicle in miles per hour, and R the radius in feet, a side friction factor was calculated. The results of these tests were plotted and reported by Barnett. The range of side friction factors varied from a low of 0.07 to a high of 0.20, with an average of 0.16 for speeds between 20 and 60 miles per hour.

There was no attempt to account for the differences in size, model, and weight of the vehicles used, variation in the condition of the tires, differences in pavement surfaces, or varying environmental and geographic factors at the test sites.

Although no driver descriptions were reported, it is presumed that the drivers represented a cross-section of all ages, driving experiences, and capabilities. The general conclusion from the tests was that a side friction factor of 0.16 was considered to be an acceptable limit based on the judgment of the drivers that participated in the testing program. Still, there was no relationship of side friction with speeds or curves and driver discomfort that could be easily measured.

Ball-Bank Indicator

In 1937 the Missouri State Highway Department first began experimenting with a ball bank indicator to measure the centrifugal force as a vehicle traverses a curve, based on earlier trial testing by the Bureau of Public Roads. This ball-bank indicator was first used in airplanes as a means by which the pilot could judge the tilt of the airplane wings in relation

to the horizon. It was a simple and inexpensive instrument developed specifically for that purpose. A steel ball sealed in a curved glass tube was free to roll traversely under the influence of the forces acting upon it. The dampening effect of the liquid in the tubes held the ball fairly steady when the aircraft was being operated. The glass tube was graduated from a center zero point outward to the ends of the tube in degrees of a full circle.

When this instrument is used by the Missouri Highway Department to determine the safe speed on curves it is mounted on a vertical surface on the vehicle. When the vehicle is exactly horizontal and on perfectly level roadway, the ball bank reading should be zero.

When the vehicle traverses a curved path, the centrifugal force on the vehicle will cause the ball to roll out to a fixed position, much as a pendulum would if supported at the center of an arc of the glass tube.

The ball-bank test runs are usually made by a driver and an observer. After checking to ensure that the ball is on the zero position when the vehicle is horizontal and that tire pressures are all equal, the vehicle is driven around the curve at a constant speed and parallel to the center lane of the curve. "Cutting the corner" is not allowed. All the forces are acting upon the vehicle during this maneuver. On superelevated curves the horizontal component of gravity force on weight of the vehicle opposes the centrifugal force. If the vehicle speed is equal to the equilibrium speed for the curve condition (the resultant of all the forces is perpendicular to the pavement surface), there is no vehicular body roll and the ball-bank indicator reads zero degrees. At speeds greater than equilibrium side friction forces acting inward react on the vehicle. If it were not for the body roll, the ball-bank angle in degrees would be a direct function relationship with the value of this side friction. The ball-bank reading in degrees is the sum of the centrifugal force angle plus the body roll minus the superelevation angle, as shown in Figure 1. It is a measure of the centrifugal forces on the vehicle and the driver in the vehicle. If there could be some relationship between perceived driver discomfort, as previously defined, and a reading on the ball-bank indicator, a link could be established between safe driving speed and curvature. After some additional testing, it was found that a 10-degree ball-bank reading corresponded approximately to a side friction factor of about 0.14 to 0.15 depending on the body roll of the vehicle.

Recommendation for Ball-Bank Readings

Since tests in 1936 had indicated that the acceptability of an average side friction factor of 0.16 related to the point of driver discomfort as previously defined, 10 degrees was selected as the value for the ball-bank indicator reading. This 10-degree reading represents a close fit to the average side friction value corresponding to the driver's tolerable limit based on "side pitch." Considering the spread in the range of the original data observations, the results were reasonably close. This 10-degree ball-bank indicator reading was the primary factor or benchmark used in future research work and application of the ball-bank indicator for curve signing.

In this same report, it was further reasoned that the higher side friction values could be tolerated for lower speeds due to less severe consequences if a driving error was committed while traversing the curve. A ball-bank reading of 12 degrees was recommended for safe speeds on curves of 30 mph or less: a reading of 14 degrees was recommended for curves where speeds were 20 mph or less. The 10-degree criteria applied to safe speeds on curves up to 50 mph. The overall effect was to recognize increased driver tolerance of discomfort at lower speeds.

Body Roll Angle

It is interesting to note that the initial testing and early experimentation work previously discussed discounted the effect of the body roll angle of the automobile. All the ball-bank readings, including the recommended criteria, are based on the computed angle, and it did not include body roll. The body roll angle on 1937-1940 vintage automobiles was about 2 degrees or less, depending on the magnitude of the centrifugal forces. Tests were conducted n 1940 by the Iowa Engineering Experiment Station staff on a wide range of speeds on varying degrees of curvature. Meanwhile, another series of tests was conducted at the General Motors Proving Ground using different models of vehicles. Based on these tests for a 10-degree ball-bank reading, the maximum roll angle was found to be 2.5 degrees and the minimum roll angle was 1.5 degrees, with only about a 1-degree difference in the automobiles tested. It was also found that as the angle increased above 10 degrees, the body roll increased proportionally. These increases were still considered to be negligible.

The effect of the body roll was to increase the tilt angle outward toward the horizontal, resulting in an increase in the ball-bank reading.

The difference in the vehicle characteristics due to body roll was considered in that only slight variations could be expected, but that the effect was not considered to be significant.

Other Variations

Further testing by the Illinois Division of Highways in 1940 on smooth pavement, slightly rough pavement, and rough pavement, found that rough or slightly rough surfaces caused computed safe speeds to be underestimated, while smoother pavements generally caused the safe speed to be consistently overestimated. The overestimation was considerably less than the underestimation of speeds, and these differences were not considered to be significant. For this reason, the application of the ball-bank indicator criteria may be questionable on rough surface or grave roads where surface variability may be extreme.

The possibility of inaccurate speedometers during testing was recognized, but it was discovered as a source of variation in the results. It is important to accurately calibrate the speedometer when conducting the trial runs using the ball-bank indicator.

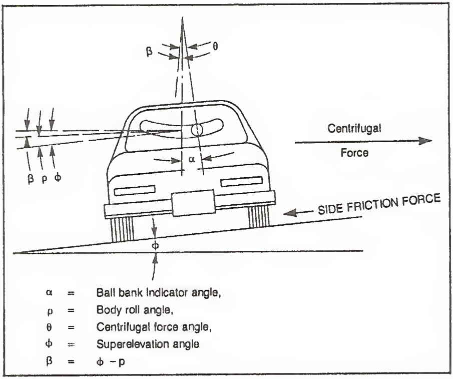

Figure 1. Geometry for ball-bank indicator.

ROUGH SURFACES CAUSED COMPUTED SAFE SPEEDS TO BE UNDERESTIMATED

History to Date

Since 1940, states have generally followed the recommendations for establishing safe speeds on curves that are contained in the report by Moyer and Berry. Between 1937 and 1944 the American Association of State Highway Officials[1] (AASHO) Special Committee on Administrative Design Policy summarized and published seven motor vehicle design policies. In 1954 the committee combined the policies into a single manual, and the 1965 AASHO and 1984 AASHTO editions of the design policies incorporated those recommendations.

Various Institute of Transportation Engineers handbooks, beginning with the 1941 editions and including the current TRANSPORTATION AND TRAFFIC ENGINEERING HANDBOOK, also followed those basic recommendations. The TRAFFIC CONTROL DEVICES HANDBOOK, published by the Federal Highway Administration as a complement to the MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES, contains similar criteria.

Design and Side Friction Factors

Side friction factors for vehicles on curves and the tolerance level of motorists have been subjects for study since the original 1936-1940 studies. Side friction has been variously described as lateral ratio, unbalance centrifugal ratio, cornering ratio, and unbalance side friction, depending upon the researcher and the county or institution performing the study work.

The values of side friction from the various studies that are plotted in Figure 2 have been used in developing the horizontal curve geometrics relationships in the various AASHTO policies on geometric design of highways. Note that the uppermost curve is used for low speed urban design in the 1984 AASHTO policy and represents an increased sense of tolerance or more discomfort to the driver in urban conditions. These side friction values have not been correlated with ball-bank indicator readings. The lower design line relationship is for rural curve design and indicates a lesser degree of driver discomfort when compared with the urban driving situation. Likewise, these values have not been directly related to the ball-bank indicator readings.

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[1] Now the American Association of State Highway and Transportation Officials.

The current generally accepted spread in the ball bank indicator readings from 14 degrees for lower speed to 10 degrees for the higher speeds reflects this similar tolerable driver discomfort behavior. Some of the earlier tests also concluded that a side friction factor of 0.21 for speeds below 20 mph and of 0.18 for speeds of 25 to 30 mph were considered to be acceptable. These side friction factors correspond to ball-bank readings of 14 degrees and 12 degrees, respectively, and are also shown in Figure 2 for comparative purposes. This spread in tolerable discomfort is generally reflected in the most current criteria in the TRAFFIC CONTROL DEVICES HANDBOOK, which is comparable to that listed in the ITE handbook.

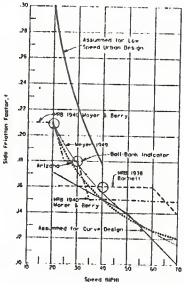


Figure 2. Side friction factors for low speed urban streets, high speed rural streets, and rural highways.

Past Survey

In 1940, 16 out of 29 reporting states used ball bank indicator criteria mostly based on the 10-degree maximum reading as the satisfactory indications of safe speed on curves. The remainder of the states either didn't respond or reported another method of determining safe curve speeds.

Current Status

A more recent poll was conducted in 1987-1988 by the author and an inquiry was made to each of the 50 states, the District of Columbia, and Puerto Rico concerning the usage of ball-bank indicator criteria for safe curve speed signing. A total of 36 respondents were received, and the results are shown in Figure 3. In summary, 3 states use the criteria in the 1984 AASHTO A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS, 5 states use the ITE criteria. 11 states use the criteria in the TRAFFIC CONTROL DEVICES HANDBOOK, and 17 states use some slight modifications of that criteria.

Usage of the modified criteria varied somewhat, but the 10 degree reading at 35 mph was still accepted as "sacred."

Generally, the 14 degree recommended reading was not used, or if it was part of the criteria, then it applied to speeds lower than 20 mph. Also, the upper limit of the 10 degree reading was greater than 50 mph in some cases. Sometimes a lower reading was used at higher speeds.

While conducting this latest survey, it was interesting to note that there were a number of states that reported that they had established a criterion for using the ball-bank indicator as shown in Figure 3. However, they didn't routinely use the ball bank indicator for determining the maximum safe speed signing on curves. Either the curves were not posted with advisory speed signs or another method was used to determine the safe curve speeds.

The ball bank procedure is a well established procedure in the United States, but it is not known how extensively it is used elsewhere. A number of foreign countries have established side friction factors for highway design purposes related to driver tolerance. They are generally within a range that is comparable with the values used in the United States.

The conclusion of the latest study on side friction factors has indicated that the current AASHTO curve design criteria provide for an acceptable level of safety for automobiles and the trucks tested. Although lateral accelerations of the vehicle were observed, there was no attempt to correlate them with ball bank indicator readings.

Summary

The ball bank indicator has been accepted by a majority of the states as a procedure for the determination of safe driving speeds on curves. The criteria that were developed in the late 1930s and early 1940s are still basically used today, practically unchanged from the initial recommendations.

Since that early era, there have been dramatic improvements in highway pavement surface materials and quality of construction, vehicle dynamics, handling characteristics (such as the lower center of gravity of modern vehicles), and suspension systems, resulting in better rideability and comfort, and automobile tire tread designs with reduced rolling resistance. These beneficial contributions and technological advancements have been recognized, yet the general consensus based on this latest survey is that the ball-bank indicator that is based on vehicles manufactured in earlier times is still an accepted method for determining maximum safe speed on curves. The ball-bank indicator criteria being used today are shown in Figure 3, but actual usage in determination of safe speeds on curves is not necessarily as widespread as illustrated in this figure.

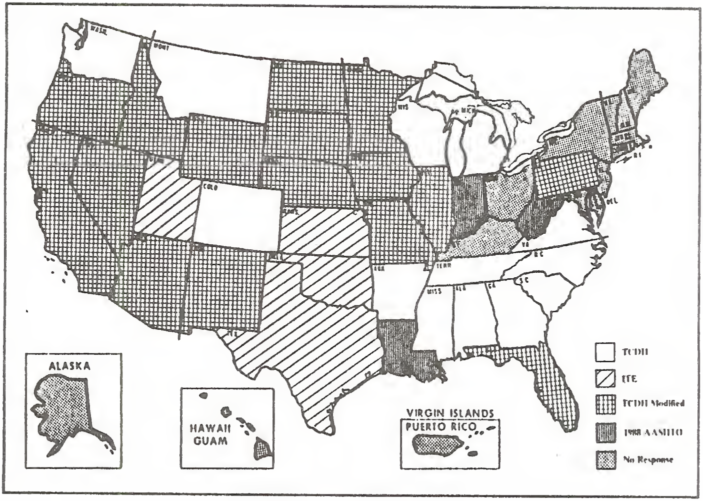
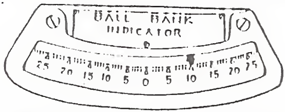


Figure 3. Ball-bank criteria usage.

HOW TO CONDUCT APPROPRIATE BALL BANK STUDY



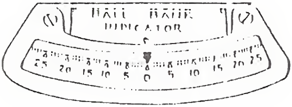
A ball bank study uses a curved level mounted a test vehicle to determine the maximum rate speed on a horizontal curve. The ball bank indicator provides an average measure of the side friction of the test car. Critical values, correlated to speed, represent the transition points at which the centrifugal force begins to cause a feeling of discomfort to the driver.

Prior to conducting the ball bank study, the vehicle must be on a flat cross slope, tires evenly inflated, loaded as it will be during the test runs, and the ball bank indicator calibrated to zero. At least two test runs in each direction should be made with the driver maintaining vehicle speed and the observer reading the ball bank indicator.

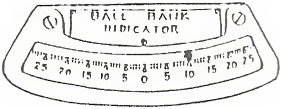
The first trial run is made at a speed below what is expected to be the maximum safe speed. Subsequent trial runs are made at speeds which increase in 5 mi/h increments. A sufficient number of test runs should be made to determine the speed required to move the ball from zero to the degree of bank specified in Figure 14 for various speed ranges. This is the safe speed for the curve.

The curve should be evaluated in both directions for the test. Many agencies prefer to sign both directions of travel at the same speed. If this is the case, then the lower speed condition should be used for both directions. If desired, a more conservative criteria of a maximum ball bank reading of 10 degrees, regardless of the speed categories represented in Figure 14, can be used.

Figure 15 can be used to help determine when corrective countermeasures at a horizontal curve are required on roadways when either the 85th percentile or the posted speed exceeds 35 mi/h. The curve is used by projecting a straight time vertically down from the safe speed determined from the ball bank study. A horizontal line is then drawn through the pretest of the 85th percentile or the posted speed. If the two lines intersect within the shaded area then countermeasures to provide a safe speed through the horizontal curve must be implemented. These countermeasures can include efforts to reduce vehicle speeds to the safe speed, such as installation of advisory speed plates on the curve warning signs, or redesigning the horizontal curve, such as increasing the superelevation or reducing the radius of curvature.

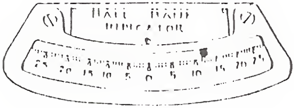


Zero Position



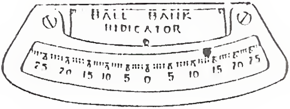
Indicates 10° Left Bank

10° Bank Indicates
Safe Speed for Speeds at
or above 35 mi/h



Indicates 12° Left Bank

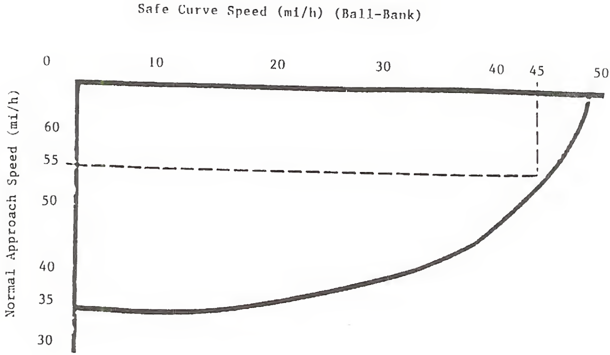
12° Bank Indicates
Safe Speed Between
20 mi/h and 35 mi/h
(20 mi/h, 25 mi/h & 30 mi/h)



Indicates 14° Left Bank

14° Bank Indicates
Safe Speeds Below
20 mi/h
(10 mi/h & 15 mi/h)

Figure 14. Procedure for determining safe horizontal curve speeds using results from ball bank indicator.



Note: If the intersecting point occurs within the shaded portion of the graph then corrective countermeasures are required.

Figure 15. Graphical method for determining when countermeasures are required for providing safe speeds through the horizontal curves for roadways with speeds equal to or greater than 35 mi/h.

General Guidelines for Ball Bank Study

- Prior to making any trial runs, the ball bank indicator should be adjusted to zero. This adjustment should be with the vehicle transversely level, loaded as it will be during the test runs, and with the times properly inflated.

- The trial runs should be performed on dry pavement. Since the speedometer and the ball bank indicator must both be observed, it is recommended to use two data collectors. If a vehicle with cruise control is used, it is possible to obtain accurate readings with one data collector. If only the driver collects the data, however, the ball bank indicator should be mounted on the steering column.

- In order to obtain a true reading, the vehicle should be driven parallel to the centerline of the curve. Flattening out the curve by driving on the inside of the centerline will yield inaccurate results.

- At least two trial runs, separated by 5 mi/h increments, should be run in each direction of the curve. At least one of these runs should be performed at the greater of the 85th percentile or the posted speed limit. Each direction of travel should be evaluated separately.

- The correct speed for the curve is that speed at which the ball bank indication exceeds the degree specified in Figure 14 for the proper speed range.

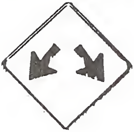
Analysis of Ball Bank Study Data

The analysis of the ball bank study consists of determining where the critical reading exists. Reviewing the ball bank data from Case Study 2, presented in Table 1, indicates that the posted speed of 55 mi/h is adequate for the northbound direction. The ball bank reading of 10 degrees was, however, experienced at 45 mi/h when the horizontal curve was transversed in the southbound direction. The safe speed in the southbound direction is, therefore, 45 mi/h. Projecting a vertical line from the posted speed of 55 mi/h, in Figure 15, indicates that the intersection of the lines is within the shaded area. Countermeasures to provide a safe speed of 45 mi/h through the horizontal curve are, therefore, required.

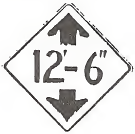
Table 1. Example results of a horizontal ball bank study.

Run Speed	Ball Bank Reading (degrees)	
	HB	SB
35	3	5
40	5	7
45	7	10
50	8	11
55	10	13

MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES
INFORMATION REGARDING BALL BANK STUDY



W12-1
24" x 24"



W12-2
36" x 36"

2C-34 Low Clearance Sign (W12-2)

The Low Clearance sign is intended for use to warn vehicle operators of clearances less than the maximum vehicle height permitted plus 12 inches. It may be erected on or in advance of the structure. If a sign is placed on the structure, it may be a rectangular shape with the legend (12)FT(6)IN.

The actual clearance is normally shown on the sign in the nearest inch not exceeding the actual clearance. However, in areas that experience changes in temperature causing frost action, an allowance, not exceeding 3 inches, for this condition, is recommended.

Where the clearance is less than the legal limit, a sign to that effect should be placed at the nearest intersecting road or wide point in the road at which a vehicle can detour or turn around.

In the case of an arch or other structure under which the clearance varies greatly, two or more signs should be used as necessary on the structure itself, to give information as to the clearance over the entire roadway.

Clearances should be checked periodically, particularly in areas where resurfacing operations have taken place.

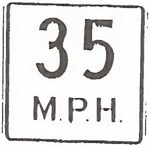
2C-35 Advisory Speed Plate (W13-1)

The advisory speed plate is intended for use to supplement warning signs. The standard size of the Advisory Speed plate shall be 18 x 18 inches. Advisory Speed plates used with 36-inch and large warning signs shall be 24 x 24 inches.

The plates shall carry the message (35) MPH in black on a yellow background except for construction and maintenance signs

The speed shown shall be a multiple of 5 miles per hour. The plate may be used in conjunction with any standard yellow warning sign to indicate the maximum recommended speed around a curve or through a hazardous location. It shall not be used in conjunction with any sign other than a warning sign, nor shall it be used alone. When used, it shall be mounted on the same assembly and normally below the standard warning sign.

Except in emergencies, or at construction or maintenance sites, where the situation calling for an advisory speed is temporary, an Advisory Speed plate shall not be erected until the recommended speed has been determined by accepted traffic engineering procedures. Because changes in surface characteristics, sight distance, etc., may alter the recommended speed, each location should be periodically checked and the speed plate corrected if necessary.



W13-1
18" x 18"
24" x 24"

2C-36 Advisory Exit Speed Signs (W13 2, W13-3)

The Exit Speed or Ramp Speed signs are intended for use where engineering investigations of roadway, geometric, or operating conditions show the necessity of advising drivers of the maximum recommended speed on a ramp.

The sign should be posted along the deceleration lane or along the ramp so that it is visible in time for the driver to make a safe slowing and exiting maneuver. Where additional advisory speed indication is needed on the ramp well beyond the gore, a standard warning sign with an Advisory Speed plate (W13 1) is to be used.

TRAFFIC CONTROL DEVICES HANDBOOK INFORMATION REGARDING BALL BANK STUDY

Advanced Posting Distance for Warning Signs

Warning signs are primarily intended to provide timely and critical information to drivers unfamiliar with the facility. Consequently, warning signs must be located in advance of the condition to which they apply. Basically, the advance posting distance is currently determined by two factors:

The 85th percentile speed or posted speed limit, whichever is higher.

The action required by the condition to be encountered.

These two factors govern the time available for the driver to see, comprehend, and react to the message by performing any necessary maneuver or action. Time factors in response to a typical traffic control device traditionally include Perception, Intellection, Emotion, and Volition, or "PIFV" (Ref. 2 3). The basic problem is then, given the vehicle speed and the reaction time of the typical driver, what is the appropriate advance posting distance? A recent revision to the MUTCD provides suggested minimum advance posting distances. The distances range from 100 feet to 775 feet.

Table 2-3 (which is shown as Table 11-1 in the MUTCD) lists the minimum sign placement distances for the following three conditions:

- Condition A - High Driver Judgment. This involves complex driving situations where the driver needs extra time to make and execute a decision (e.g. a lane change or merge on a high volume³high speed roadway.)
- Condition B - Stop Conditions. This covers situations in which the driver may be required to come to a complete stop (e.g., signalized or STOP sign intersection, pedestrian crossing, crossroad, etc.)
- Condition C - Deceleration Condition. In this case the driver will likely be required to decrease speed in order to take the proper action or maneuver (e.g. to slow for a turn, curve, dip, etc.)

Under Condition A (High Judgment Needed), a supplementary legend specifying distance to the condition should be used in urban areas if there is an intersection between the advance warning sign and the condition. Otherwise, the driver might

become confused and interpret the sign to mean that the condition is at the intervening crossroad. For conditions B and C, the distances are based on a sign legibility distance of 125 feet which would be provided by 30 and 36 inch signs. If 48-inch signs are used, the legibility distance may be increased to 200 feet which would allow a reduction of 75 feet in the placement distances given in Table 2-3.

Height and lateral placement of warning signs should conform to the general specifications for the placement of signs, as prescribed in Section 2C-3 of the MUTCD). Signs warning of conditions which ar temporary or intermittent n occurrence F(e.g., road repairs) are normally mounted on portable supports. Care should be taken to insure that these signs are clearly visible to approaching traffic.

Signing Curves

The warning signs such as the turn sign, curve sign, reverse curve sign, etc., are part of what is known as the alignment series. Shaped arrows are used to indicate the roadway alignment to be expected. Table 2-3 can be used to determine the advance posting distance for alignment warning signs. The point of reference used is the point at which the curve begins. Except where two successive curves qualify as combination curves, advance posting of one curve is never ahead of the previous curve.

Whether or not a particular curve needs to be signed is based on the recommended speed at which the curve may be traversed. This speed may be determined by the use of the curves in Figure 2 6, by the use of a ball bank indicator (Figure 2 7), or by mathematical computation.

The curves given in Figure 2 6 are used when the radius, R, and superelevation, e. of the curve are known. The radius and super-elevation of the curve may be obtained from actual measurement or from construction plans of the roadway. The combination of radius and super-elevation giving the lowest speed for the curve should be used.

The ball bank indicator is a curved level which is used to determine the safe speed around a curve as indicated by trial speed runs. The trial speed runs involve the use of the vehicle and ball bank indicator to show the combined effect of the body roll angle, the centrifugal force, and the superelevation angle.

The device is mounted in the car and checked to assure that the ball within the level is on zero when the car is on a level surface and loaded as it will be during the run. It is desirable

TABLE 2, ADVANCE WARNING SIGN PLACEMENT

Suggested Minimum Warning Sign Placement Distance - Feet

GENERAL WARNING SIGNS

Posted on 85 speed mph percentile speed mph (use higher	Condition A high judgment needed (10 Sees PHV)	Condition B STOP condition	Condition C Deceleration speed conditions to listed advisory speed MPH (or desired speed at condition)				
		0	10	20	30	40	50
20	175	(')	(')				
25	250	(')	100				
30	325	100	150	100			
35	400	150	200	175			
40	425	225	275	250	175		
45	550	300	350	325	250		
50	625	375	425	400	325	225	
55	700	450	500	475	400	300	
60	775	550	575	550	500	400	300

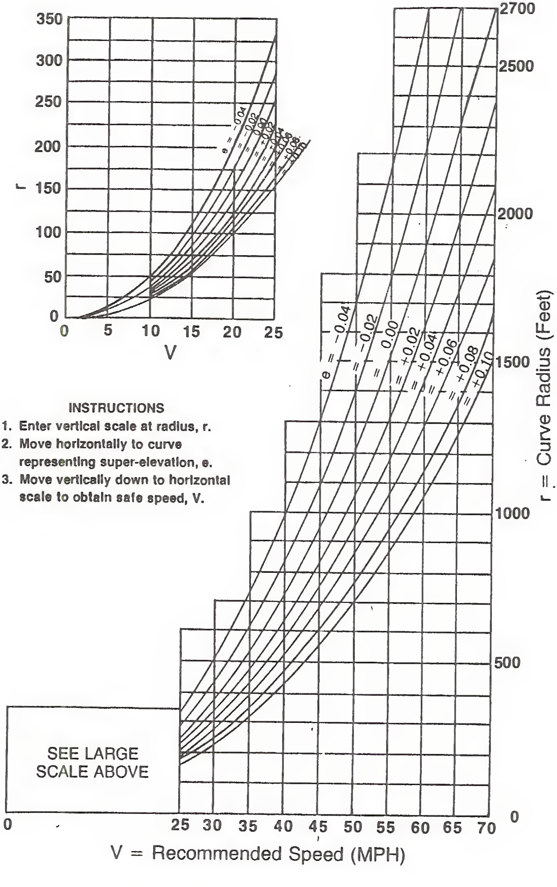
Distances shown are for level roadways. Corrections should be made for grades. Distances based in 36 inch signs. If 48 inch signs are used, the legibility distance may be increased to 200 feet. This would allow reducing the distance by 75 feet.

In urban areas, a supplementary plate underneath the warning sign should be used specifying the distance to the condition if there is an in between intersection which might confuse the motorist.

Distance provides for a second PHV 125 feet Sign Legibility Distance, Braking Distance for Conditions B and Comfortable Breaking Distance for Condition C as indicated in A POLICY ON GEOMETRIC DESIGN OF RURAL HIGHWAYS, 1965, AASHTO, Figure VIII-15B.

No suggested minimum distance provided. At these speeds, sign location depends on physical condition at site.

Typical signs for the listed conditions in Table 11 1: Condition A: Merge, Right Lane Ends, etc.; Condition B: Cross Road, Stop Ahead, Signal Ahead, Ped-Xing, etc.; Condition C: Turn, Curve, Divided Road, Hill, Dip, etc.



INSTRUCTIONS

1. **Enter vertical scale at radius, r.**
2. **Move horizontally to curve representing super-elevation, e.**
3. **Move vertically down to horizontal scale to obtain safe speed, V.**

Figure 2-6. Recommended Safe Speed.

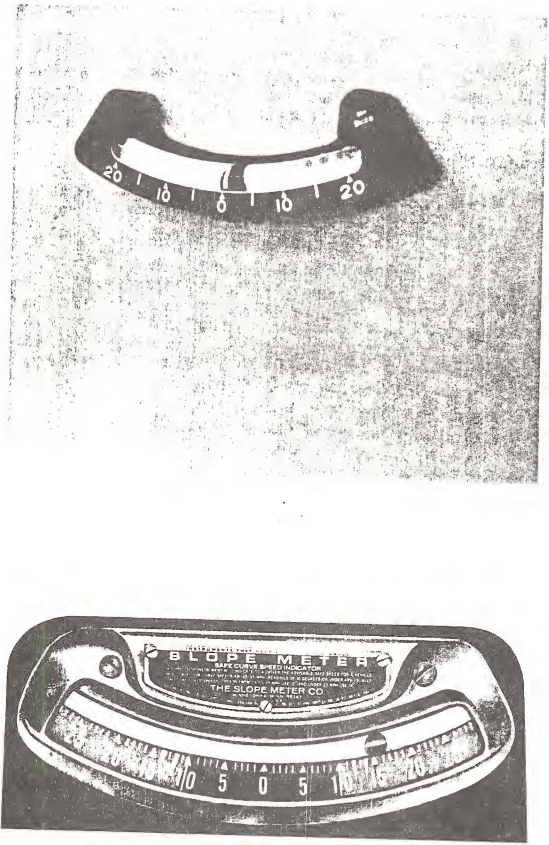


Figure 2-7. Ball Bank Indicator

You should use two people during the run so that the traffic, the speedometer, and the ball-bank indicator can be monitored throughout the trial speed runs. To obtain a true reading on the ball-bank indicator, can be monitored throughout the trial speed runs. To obtain a true reading on the ball-bank indicator, the car must be driven parallel with the center line of the curve. The common practice of flattening out a curve by driving on the inside of the curve at the center should be avoided.

The first trial run is made at a speed somewhat below the anticipated maximum safe speed. Subsequent trial runs are conducted with 5 mph speed increments. If a reading of 14° or greater occurs at 20 mph or less than the safe speed is below 20 mph. the curve should be signed for that speed, i.e. 10 or 15 mph, at which a 14° reading occurs. A reading of 12° at a trial speed of 20, 25, and 30 mph indicates that the trial speed, i.e., 20, 25, or 30 mph is the safe speed. A reading of 10° at speeds of 35 mph or greater indicates a safe speed of 35 mph or greater.

Curves should be evaluated in both directions when using this method. Many times it is preferred to use the lower speed condition for signing both approaches.

While many agencies use the 14°, 12°, 10° criterion for signing curves, other agencies use more conservative criteria. For example, a 10° reading at any speed would indicate the maximum safe speed in some States. Prior to applying this procedure a check should be made to insure what the accepted criteria are for the area in question.

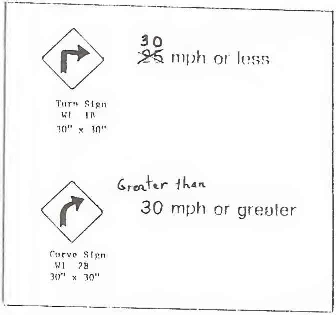


Figure 2-8. Appropriate Use of Turn Sign and Curve Sign.

A third method for determining the safe speed of a curve is to apply the following formula:

$$V - 15 R (e \; 1 \; f)$$

where:
V - Speed in miles per hour
R - Radius of super elevation in feet per foot
e - Rate of super elevation in feet per foot
f - Safe coefficient of side friction

The speed determined by any one of the above methods is the basis for arriving at the recommended speed for the curve which, in turn, determines whether a turn or curve sign should be used. Figure 2-8 shows the appropriate sign to be used as indicated by the speed graph, the ball-bank indicator, or by mathematical techniques.

Advisory Speed Plate

The supplemental advisory speed plate may be used when the recommended speed is equal to, or less than, the legal speed limit. No advisory speed plate is used when the safe curve speed is greater than the legal speed limit.

Combination Curves

A combination curve consists of two successive curves. They may be connected with or without a short tangent section, and they may be in the same or in opposite directions. The recommended speed for the combination will be the lower recommended speed of the two curves. If either of the curves requires a turn sign, such a sign would be used for the combination curve.

A reverse curve is a type of combination consisting of two curves in opposite directions separated by a tangent of less than 600 feet. The Reverse Curve (W1-4) and Reverse Turn (W1-3) signs are intended for use under these conditions. The lower of the recommended speeds for the two curves will prevail. A combination curve with curves in opposite directions separated by more than 600 feet of tangent should be signed as separate curves.

The Reverse Turn sign is intended for use if either or both of the curves require a turn sign. It is often advantageous to supplement the Reverse Turn sign (W1-4) and appropriate speed plate in advance of the second curve.

Another type of combination curve sign, the Winding Road sign (W1-5) may be used where there is a succession of three or more curves. Where there are fewer than three curves in succession, one or two Turn, Curve, Reverse Turn, or Reverse Curve signs should be considered.

The Reverse Turn, Reverse Curve, and Winding Road signs are provided in left and right designs. If the first curve is to the left, a "left" sign is used and if the first curve is to the right, a "right" sign is used.